STATIC AND DYNAMIC FATIGUE TESTS ON CARBON FIBRE TYPE II MANUFACTURED BY MORGANITE MODMOR LIMITED

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OCTOBER 1974

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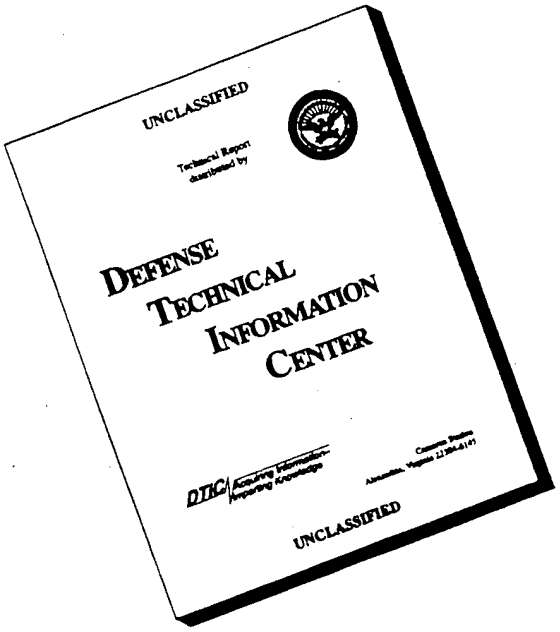

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BRISTOL COMPOSITE MATERIALS ENGINEERING LIMITED

Static and dynamic fatigue tests on carbon fibre type II manufactured by Morganite Modmor Limited

F i n a l R e p o r t

BCME/ED/R/20

Prepared by W.J.P. Parnell for
European Space Research Organisation
Contract No. 1486/71AA, Rider No. 2

WAB/WJPP/MM

October, 1974

SUMMARY

A study has been made of the application of fibre reinforced composite materials to the construction of a lightweight, long life, high pressure, gas storage vessel for satellite attitude control systems.

The operational requirements demand good dynamic fatigue, long term pressure holding capability with negligible leakage and compatibility with a wide range of media.

These requirements can be met by the use of composite materials manufactured from the recently introduced carbon and PRD.49 fibres which, unlike glass fibre composites, have a stiffness comparable with metal materials.

In addition, these materials have excellent specific tensile strength and good resistance to ageing and fatigue, such that vessels can be constructed with a "long term" performance rating, much higher than that available from metallic structures.

This document reports on the results of tensile static, dynamic fatigue and very long term static fatigue strength tests with type II carbon fibre composite structure NOL rings.

CONTENTS

1 INTRODUCTION:

This report defines the test results obtained on carbon fibre type II and supplements the programme of work contained in document RRCM/ED/P/16 dated 8 May, 1972:

> " Test programme to evaluate the static and dynamic fatigue performance of PRD.49 III and carbon fibre composites in relation to their application for long life pressure vessels."

The test specimens were manufactured in the form of NOL rings by filament winding with a liquid epoxy resin system. The tests which have been completed include the long term creep test. From the results of those tests was evaluated the basic data for static strength and dynamic fatigue of carbon fibre type II.

For completeness, the results contained in the interim report are also represented in this final report.

Specimen details were as follows:

Material:	Type II Modmor carbon fibre
Manufacturer:	Morganite Limited
Specification No:	Type II (LL) CQ 10 untreated
Number of filaments in tow:	10,000
Tex:	0.8264 grams

2 WINDING TECHNIQUES:

All specimens were wet wound using 828/DDM, resin/hardener system. From the results of preliminary winding trials for wet wound NOL rings, using carbon fibre type II (Morganite Modmor Limited) a winding tension to be used was established of 2 kg per tow (equivalent to a fibre stress of 0.0414 GN/m^2 (6,003 lb/in^2).

A constant number of ten passes or revolutions on each NOL ring was used to ensure a consistent and determinable volume of fibre in each specimen.

3 STATIC ULTIMATE TENSILE STRENGTH TEST RESULTS:

Six NOL rings were wound using carbon fibre type II (Morganite) with a fibre volume fraction as follows:

Rings Nos. 1,2 and 3 — Mean fibre volume: = 63.5% (from 20 checks)

" " 4,5 and 6 — Mean fibre volume: = 61.6% (from 10 checks)

The following results were obtained:

T a b l e 1

Specimen No.	Load kg	Load (lb)	Composite stress GN/m^2	Composite stress (lb/in^2)	Fibre stress GN/m^2	Fibre stress (lb/in^2)
1	1945	(4287)	1.364	(197,770)	2.148	(311,450)
2	1815	(4000)	1.294	(187,580)	2.037	(295,402)
3	1855	(4088)	1.369	(198,470)	2.156	(312,551)
4	1715	(3780)	1.262	(182,927)	2.048	(297,000)
5	1625	(3582)	1.157	(167,752)	1.878	(272,350)
6	1750	(3857)	1.282	(185,880)	2.081	(301,753)

Mean load = 1784kg(3934 lb)

Standard deviation= 103.0

One standard deviation covers the range 1681 kg (3705 lb) to 1887 kg (4159 lb).

Two standard deviations cover the range 1578 kg (3478 lb) to 1990 kg (4386 lb).

Hence, the design ultimate load used for the purpose of setting the static and dynamic fatigue stress levels was taken as 1578 kg (3478 lb). This gave a fibre stress of 1.821 GN/m^2 (264,050 lb/in^2).

4 DYNAMIC FATIGUE TEST:

4.1
Three NOL rings wound with ten passes of carbon fibre type II were subjected to the fatigue cycle test for each ring as follows:

a) 200 cycles at
1 cycle per 2 minutes

b) 200-1,000 cycles at
2 cycles per 1 minute

With load range per cycle 80 kg (176 lb) to 1420 kg (3130 lb) this is 5% and 90% respectively of the "design" failing load. The 1420 kg load is equivalent to a fibre stress level of 1.639 GN/m^2 (237,655 lb/in^2).

No failures occurred during this test.

4.2
The three NOL rings tested in section 4.1, as above, after completing the 1,000 cycle test, were statically tested and gave the following results:

NOL Ring No.1	Failed at 1910 kg	(4210 lb)
" " " 2	" " 1850 kg	(4077 lb)
" " " 3	" " 2000 kg	(4408 lb)

Mean failing load = 1920 kg (4232 lb)

This is greater than the mean failing load of 1784 kg (3934 lb) derived from the results of six NOL rings statically tested (paragraph 3, table 1).

4.3
This material so far has given better structural results than the carbon fibre type III tested previously in this programme, as shown below:

Carbon fibre	Mean static composite structure stress	Mean static composite structure stress after fatigue loading
Type III	1.26 GN/m^2 (182,700 lb/in^2)	Only one specimen completed 1000 cycles without failure and gave 1.167 GN/m^2 fibre stress (169,225 lb/in^2)
Type II	1.384 GN/m^2 (200,680 lb/in^2)	1.490 GN/m^2 (216,090 lb/in^2)

This is because difficulty was found in achieving a high fibre volume fraction with type III fibres.

4.4
No damage was detected during or after 1000 cycles up to 90% of the design failing load.

5 STATIC FATIGUE AND CREEP TEST:

5.1
Three NOL rings wound with carbon fibre type II (Morganite) were subjected to 100 cycles at 1 cycle per minute and load range per cycle was 20 kg (44.0 lb) to 631.0 kg (1391 lb) which is 40% of the "design" failing load, which is 1578 kg (3478 lb).

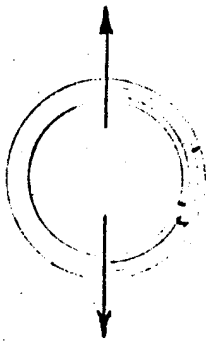
No failure occurred.

5.2
All NOL rings tested as described in above paragraph 5.1 to simulate ground service use were finally placed in the creep test facility at 86% of the "design" failing load, ie, 1357 kg (2991 lb) representing a fibre stress of 1.566 GN/m^2 (227,070 lb/in^2) for a creep test scheduled to last for a period of 10,000 hours. The deflections recorded are shown in graphs Nos. 1,2 and 3.

5.3
After the creep tests were completed on two NOL rings wound with carbon fibre, type II, they were tested under the residual static load up to failure. The results and details of the structure behaviour of the specimens are shown in the Summary Table II.

5.4
A creep distortion varying between specimens from 5% to 8% of initial deflection was measured.

5.5
Interlaminar shear characterised the failure mode of the Type II carbon fibre static fatigue specimens. The failure mode is shown in the following sketch:



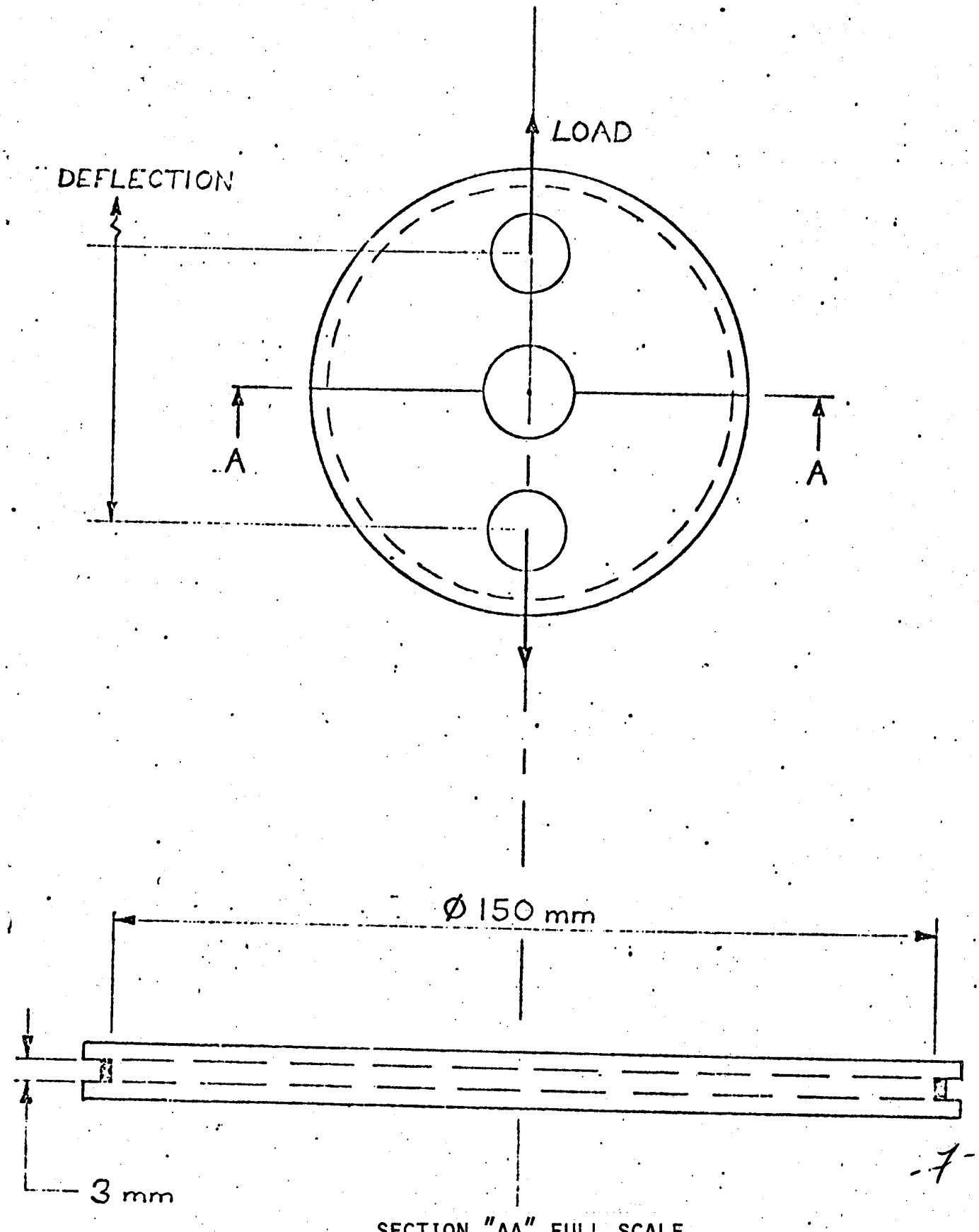
NOL ring - typical interlaminar shear

This mode of failure occurred due to weakening of the resin matrix after long exposure to creep distortion.

LABORATORY MATERIAL CHECKS:

Material:	Carbon fibre type II	Morganite Modmor Limited
Density:		1.711 g/cc (.062 lb/in^3)
Weight per metre:		.8260 gms
" " 10 feet:		2.158 gms
Roving strength 250 mm (gauge length)		1.746 GN/m^2 1.634 " 1.700 " 1.577 " 1.906 "
Average roving strength:		1.725 GN/m^2
Appearance:		good
Fibre volume fraction from single NOL ring		Percentage of fibre by volume
1) from acid digestion:	mean	67.25%
2) from Quantimet determination:	mean	62.55%
3) from thickness:		60.0%
Average composite density:		1.532 g/cc (.0553 lb/in^3)
Interlaminar shear:	mean	.0353 GN/m^2 (5120 lb/in^2)

TYPICAL NOL RING TEST SPECIMEN



SECTION "AA" FULL SCALE

8 CONCLUSION:

8.1
Carbon fibre type II gave slightly higher fibre strengths than type III, although the scatter in results was greater.

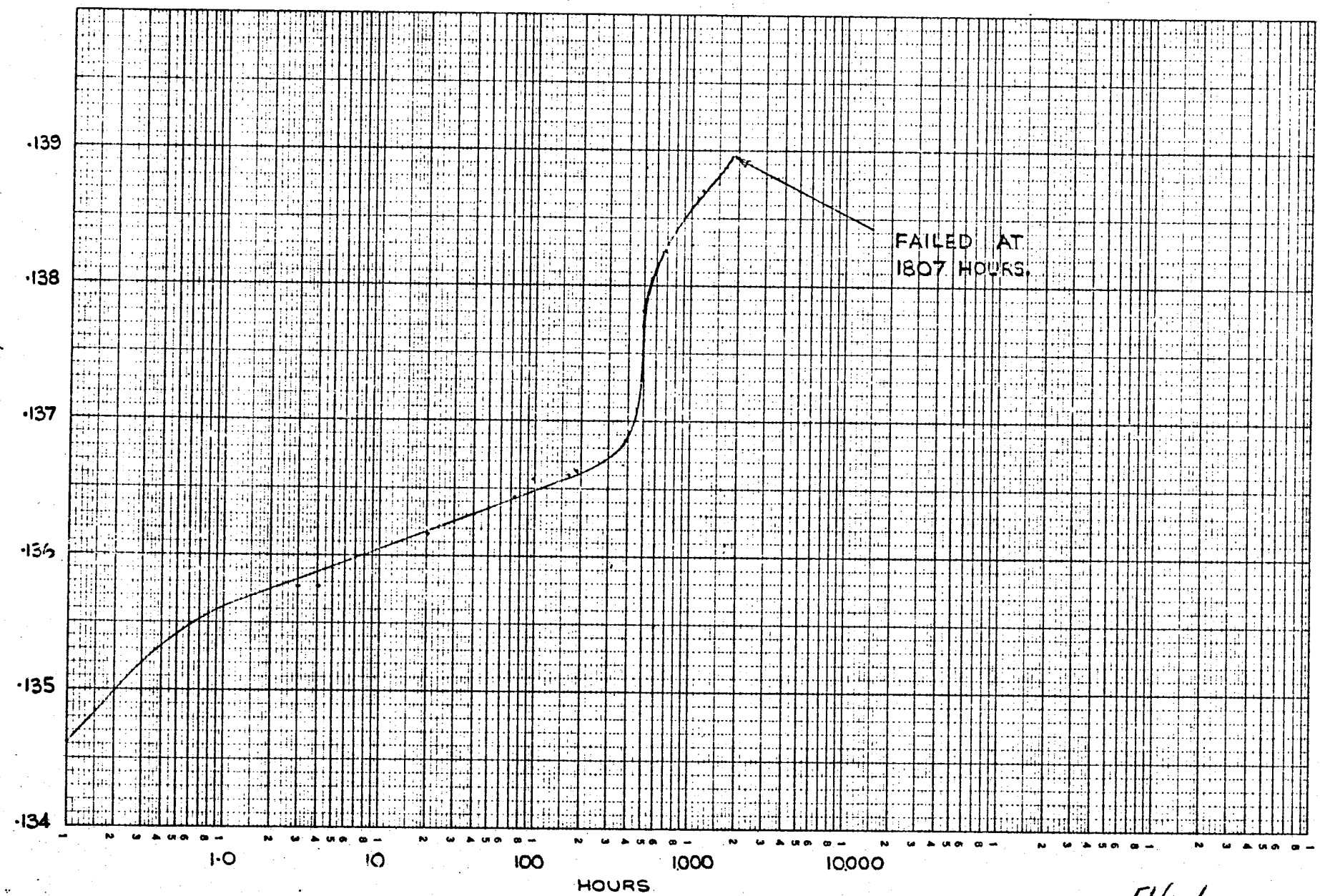
8.2
The handling qualities of type II carbon fibre are good and a greater tow tension could be applied compared with carbon fibre type III. It was possible to achieve a greater volume fraction of fibre in the composite.

8.3
Static fibre failing stress levels for NOL rings wound with carbon fibre type II are higher than those for rings wound with carbon fibre fibre type III.

In terms of long term creep loads applied to the NOL rings, those wound with carbon fibre type III show higher failing stress than those wound with carbon fibre type II.

8.4
One specimens of the three failed in static fatigue test after only 1807 hours compared with no failure of the other two specimens after 10,000 hours. One explanation of this failure is that the static load level was set at 86% of the ultimate design strength of two standard deviations below the mean of the results of static tests on six other specimens. The static load level of the broken specimen therefore may have been almost that of the ultimate strength of that specimen if it had been constructed at the lower performance band indicated by the limited test sample made.

ESRO N.O.L. RING STATIC FATIGUE CREEP
SPECIMEN No. 1. CARBON FIBRE TYPE II.



TIME AT 86% OF DESIGN FAILING LOAD.

FIG. 1

ESRO N.O.L. RING STATIC FATIGUE CREEP
SPECIMEN No. 2 CARBON FIBRE TYPE II.

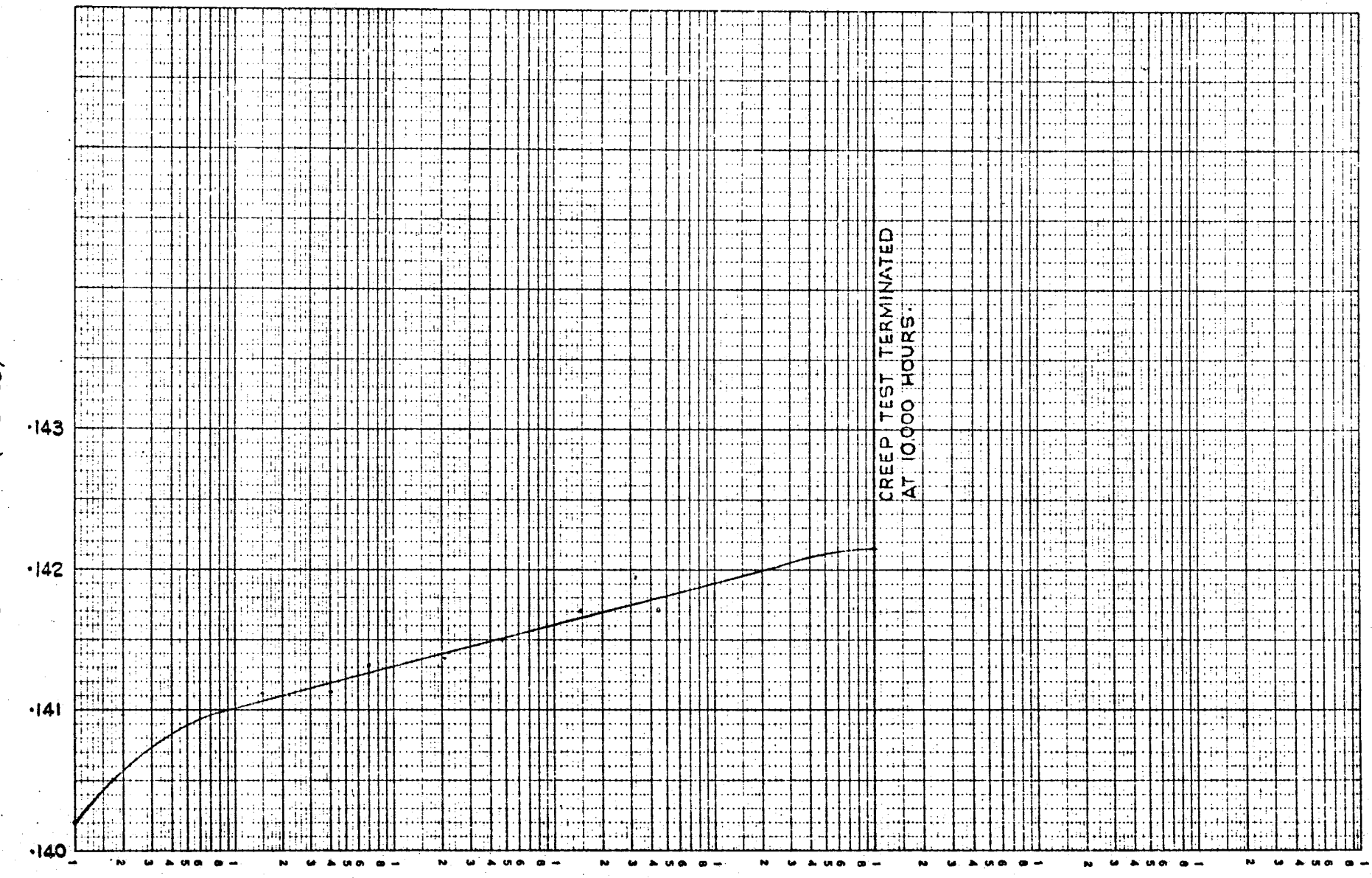


FIG. 2

ESRO N.O.L. RING STATIC FATIGUE CREEP
SPECIMEN No. 3 CARBON FIBRE TYPE II.

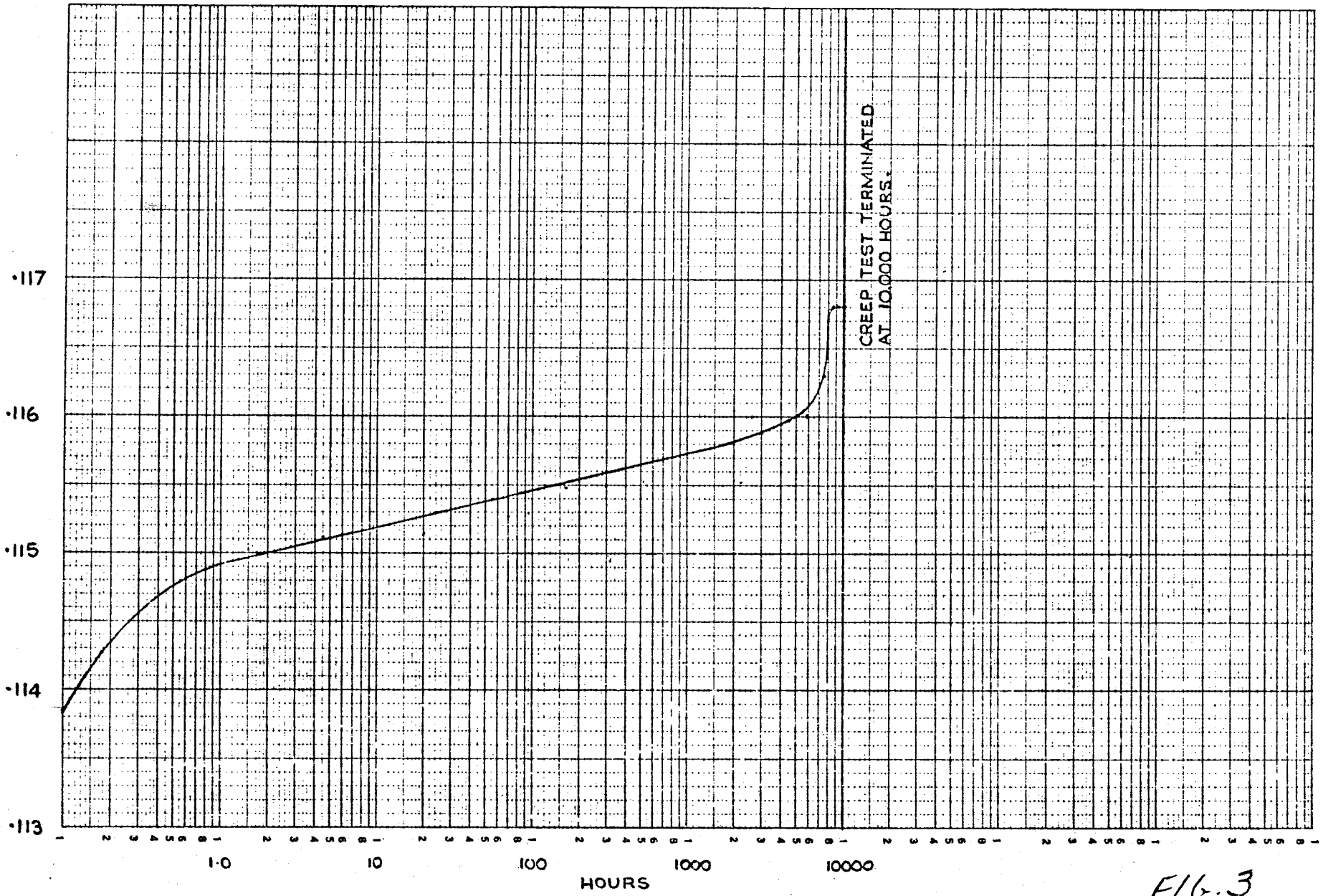


FIG. 3

ESRO. N.O.L. RINGS CARBON FIBRE TYPE II.

INSTRON GRAPH OF STATIC LOAD UP TO FAILURE

ON RINGS AFTER 10.000 HRS. STATIC FATIGUE CREEP.

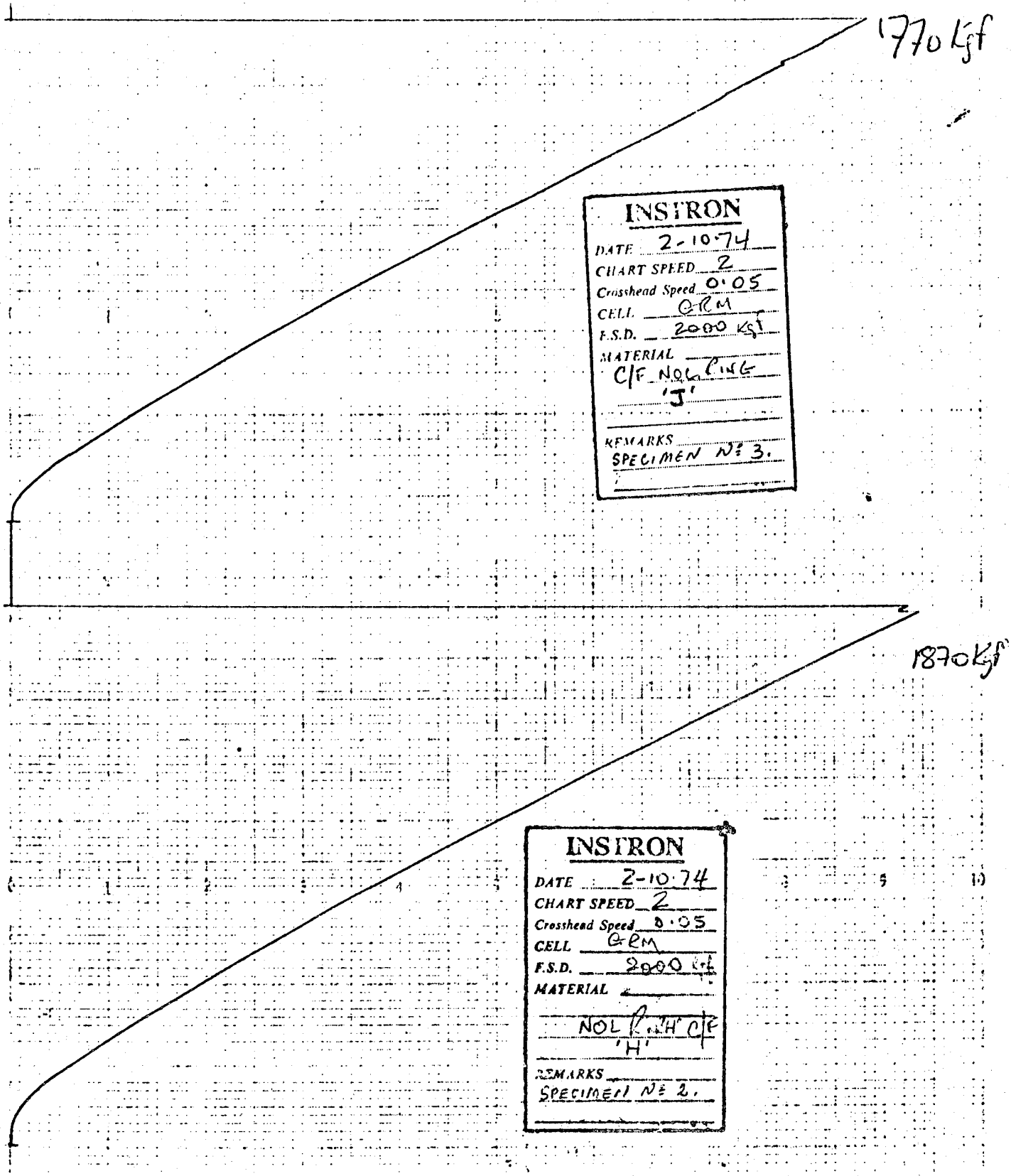


Table II

SUMMARY OF RESULTS: I Static tensile
II Dynamic fatigue
III Fatigue creep strength

(For comparison ref BCME/ED/P/16, Rider 1)

			Carbon fibre type II 10 passes per NOL ring	Carbon fibre type III 7 passes per NOL ring
	Fibre density:		1.711 g/cc	1.74 g/cc
Volume fraction (by acid digestion)	maximum:		74.00%	55.0%
	average:		67.25%	52.5%
	minimum:		64.30%	50.0%
I Ultimate NOL.ring static tensile strength: fibre stress:	maximum:		2.156 GN/m^2(312,551)	2.710 GN/m^2
	average:		2.058 GN/m^2(298,410)	2.402 GN/m^2
	minimum:		1.878 GN/m^2(272,350)	1.960 GN/m^2
II Dynamic fatigue test in tension:			No.NOL.ring	No.NOL.ring
Fatigue maximum fibre stress and number of cycles completed:		1)	1.639 GN/m^2(237,655) 1000 cycles	1) 1.524 GN/m^2 failed at 25 cycles
		2)	1.639 GN/m^2(237,655) 1000 cycles	2) 1.524 GN/m^2 1,000 cycles
		3)	1.639 GN/m^2(237,655) 1000 cycles	3) 1.430 GN/m^2 failed at 493 cycles
Static fibre failing stress after 1,000 cycles (residual strength)	maximum:		2.308 GN/m^2(334,691)	1,924 GN/m^2
	average:		2.216 GN/m^2(321,305)	1.625 GN/m^2
	minimum:		2.135 GN/m^2(309,558)	1.430 GN/m^2

III Fatigue and creep tests on NOL.rings in tension:	No.NOL.ring. 4	5	6	4	5	6
Static fibre stress GN/m^2	1.606 (232,870)	1.460 (211,440)	1.400 (203,160)	1.396	1.396	1.270
Time under static load/hrs	failed at: 1,807	10,000	10,000	9106	9104	9104
Maximum creep deflection(mm)	3.53	3.62	2.96	2.36	2.78	2.721
Static fibre failing stress after creep test GN/m^2 (residual fibre stress)	-	2.01 (291,321)	1.827 (264,951)	1.792	2.105	1.891

Note: all figures in brackets are lb/in^2